J. Mt. Sci. (2012) 9: 372–384
DOI: 10.1007/s11629-009-2172-2

Forest Biodiversity Assessment in Peruvian Andean Montane Cloud Forest

Alicia Ledo[1]*, Sonia Condés[1], Iciar Alberdi[2]

1 Universidad Politécnica de Madrid. Escuela Técnica Superior de Ingenieros de Montes. Ciudad Universitaria, sn. 28040, Madrid, Spain

2 CIFOR-INIA Ctra. de La Coruña Km 7.5, 28040, Madrid, Spain

**Corresponding author, e-mail: alicialedo@gmail.com; sonia.condes@upm.es(Sonia Condés); IFNBiodiv@mma.es(Iciar Alberdi)*

Abstract: Cloud forests are unusual and fragile habitats, being one of the least studied and least understood ecosystems. The tropical Andean dominion is considered one of the most significant places in the world as regards biological diversity, with a very high level of endemism. The biodiversity was analysed in an isolated remnant area of a tropical montane cloud forest known as the "Bosque de Neblina de Cuyas", in the North of the Peruvian Andean range. Composition, structure and dead wood were measured or estimated. The values obtained were compared with other cloud forests. The study revealed a high level of forest biodiversity, although the level of biodiversity differs from one area to another: in the inner areas, where human pressure is almost inexistent, the biodiversity values increase. The high species richness and the low dominance among species bear testimony to this montane cloud forest as a real enclave of biodiversity.

Keywords: Andean Range; Biodiversity; Dead wood; Montane forest; Species composition; Stand structure; Tropical forest

Introduction

Tropical Montane Cloud Forests (TMCF) have been identified as one of the most biologically diverse ecosystems in the world (Gentry 1992; Hamilton et al. 1994), displaying a high level of species endemism (Luna-Vega et al. 2001). TMCF is recognized as a biodiversity hotspot (Myers et al. 2000). Local endemism in South American cloud forests ranges from 10-24%, suggesting that unique evolutionary processes may operate in these areas (Gentry 1992). In Peru the greatest numbers of endemic species are found on the slopes of the Andes between 2,500 and 3,000 m (Van der Werff and Consiglio 2004).

The term Montane Cloud Forest has been widely used since the Puerto Rico Symposium (1993) and the Montane Cloud Forest Initiative formed in 1999 [a partnership comprising the United Nations Environment Progamme (UNEP), the UNEP World Conservation Monitoring Center (WCMC), the International Union for Conservation of Nature (IUCN), and the United Nations Educational, Scientific and Cultural Organization (UNESCO)]. Earlier research and habitat descriptions for TMCF were provided by Grubb et al. (1963), Stadtmüller (1987) and Hamilton (1995). Cloud forests are characterized by the presence of persistent or frequent fog or wind-driven cloud (Stadmuller 1987; Bruijnzeel and Veneklaas 1998). The net precipitation is significantly enhanced by direct canopy interception of cloud water (Cavelier

Received: 15 April 2011
Accepted: 22 December 2011

et al. 1997). The hydrological cycle is vital to the continuity of plant and animal species living within the forest (Foster 2001; Gomez-Peralta et al. 2008). Many TMCF habitats represent the last remnants of native vegetation on tropical mountains (Hamilton 1995, Bubb et al. 2004). It is important to develop a worldwide inventory, to support and conduct further studies and to establish monitoring programs (Hamilton et al. 1994).

Andean forests have one of the highest rates of species disappearance (Churchill et al. 1995; Gentry 1992) with up to 90% of TMCF species having been lost in some northern Andean cloud forest habitats (Hamilton 1995). Land-use changes in areas of cloud forest affect ecosystem functions irreversibly (Ledo et al. 2009; Hamilton et al. 1994). Activities such as the conversion of forested land to agricultural land, fuel-extraction (Sarmiento 1993) or illegal logging (Aubad et al. 2008), has caused the disappearance and fragmentation of TMCF (Young and León 1993).

Three key components of biodiversity can be recognized in forest ecosystems (Schulze and Mooney 1994): composition, structure and function which can be expressed as indicators relating to structure and composition of the forest. However, some structural indicators may be functional indicators such as dead wood, which is important to nutrient recycling and provides habitat for numerous plants, animals and fungi (Ferris and Humphrey 1999; Hunter 1990).

The objective of this study was to further our knowledge of the biodiversity (focusing mainly on composition, structure and dead wood) in TMCF. We attempt to provide baseline data on TMCF habitat components in a remnant cloud forest fragment known as “Bosque de Neblina de Cuyas”, located in the Western Andean Cordillera in North Peru. This site is of particular relevance, being the last area of well-preserved forest in the Western Cordillera in North Peru. The ecological information recorded in this study will also be useful to develop local education and conservation programs (Foster 2001; Hamilton 1995; Oosterhoorn and Kappelle 2000).

1 Material and Methods

1.1 Study site

The study site was located in the Bosque de Neblina de Cuyas, situated on Cerro Chacas, in the Ayabaca province of the Piura region (northern Peru, in the western Andean range). The study site consisted of wet montane forest (bh-M, Holdridge classification 1967), which is classified as either tropical upper montane rainforest (Grubb et al. 1963) or an upper montane forest (Whitmore 1998). The UTM area coordinates 643230 to 643740 W and 9493300 to 9490499 S, in the 17S zone (Datum WGS84) (Figure 1).

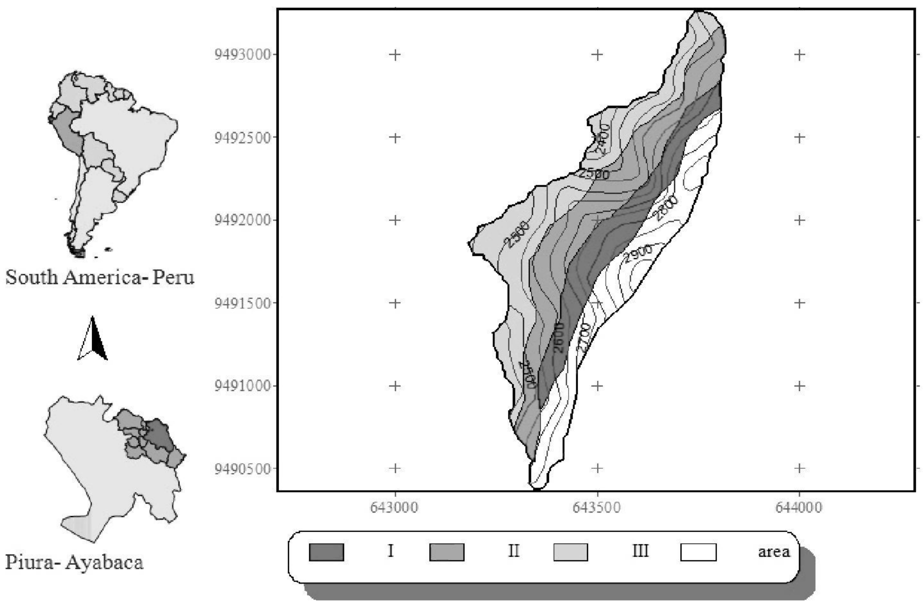

Figure 1 Map of the study area

The study area is characterised by irregular surfaces and steep slopes. Altitudes range from 2,359 mASL to 3,012 mASL. The average slope is 29% but in many cases, the slope is greater than 90%. The primary part of the study area faces south-west, with two roads delimiting the upper and lower limits. The total size of the study area was 171 ha. The climate is considered cold temperate, with a dry winter, according to the Köppen classification (1931). The mean temperature is 15 °C (range 8.5-18°C). The relative humidity value is 100% during the rainy season (November-May) and 75-80% in the dry season. The persistence of fog is slightly above half a day in the dry season and higher in the rainy season, where the clouds can cover the forest for extended periods. The mean precipitation is 1750-2000 mm/year. However, this figure increases notably during the El Niño Southern Oscillation (ENSO) years (Romero et al. 2007). The soil is podzol-like, completely covered with decayed leaves (Figure 2). There is a notable presence of cryptogams, forming a distinctive element in cloud forest (Foster 2001; Hamilton 1995), with moss often covering 100% of the trunk (Figure 2). There is a high level of endemism and several taxa occur on the IUCN red list Version 2010.4 (Appendix 1).

Figure 2 Pictures of the studied forest: moss in the forest (above left); epiphytes covering a trunk (above right); soil covered by organic material (below left) and general view of the interior of the forest (below right)

The study area was divided into four areas, which corresponded to altitudinal ranges. Elevation is strongly correlated with community composition and diversity in tropical montane forest (Munishi et al. 2007) with biodiversity in Andean forests often inversely proportional to elevation, reaching the maximum peaks of forest diversity between 500 and 2,000 m a.s.l. (Gentry 1988). The first forest area (stratum I) corresponded to the upper zone; the second (stratum II) was situated in the mid-zone and the third (stratum III) was located in the lower zone. The degraded area was not included in this study; it was separated by the low degree of naturalness (Figure 1). A random sampling, without replication, was carried out in each stratum. Forty-two random square plots (20 × 20 m) were established throughout the three strata, where the number of plots in each stratum was proportional to the area of the stratum (12 plots in stratum I, 14 plots in stratum II and 16 plots in stratum III). The forest inventory was carried out between January and May of 2006. The total size of the study area, once the degraded area had been excluded, was 130.9 ha. The total monitoring area was 1.68 ha; comprising 1.3% of the study area.

1.2 Measurements and data analysis

The analysis focused on three core variables for biodiversity assessment: (i) composition, (ii) structure and (iii) dead wood. Woody plant species composition was analysed to calculate diversity and ecosystem variation in each field stratum and then between strata to calculate diversity in order to detect habitat difference among zones within the forest. An inventory of plant taxa is in Table 1.

The diversity levels in each stratum were compared with Rènyi's diversity curves (1970). Whittaker's (1960) and Routledge's (1977) indexes were calculated as a measure of ecosystem variability within each field stratum while Sørenson indexes (1957) were calculated to analyse the similarity between strata (Table 1).

Structure was calculated as: (a) Horizontal structure which consisted of different successional stages and included the number of trees per ha, basal area, quadratic average diameter and standard deviation of tree diameter at breast height based on the following diameter classes: DBH ≤ 2.5 cm; 2.5 <

DBH ≤ 7.5 cm; DBH > 7.5 cm, and (b) Vertical structure which assessed the number of layers in the forest stand and dominant height, estimated as the mean height of the 100 tallest trees per ha, the Shannon-Wiener index applied to vertical structure, *H'* (Shannon - Wiener 1949) and the modified Shannon-Wiener index including species composition, H_e (Meyer 1999). The Shannon-Wiener indexes were calculated for the proportion of trees in different stand layers--layer 1: 100 - 80% of maximal tree height (h_{max}), layer 2: 80 - 50% of h_{max}, layer 3: 50 - 0% of h_{max}.

$$H' = -\sum_{i}^{N} p_i \ln p_i$$

where $p_i = \frac{n_i}{N}$, n_i= number of trees in height layer *i*, *N*= total number of trees in the stand.

$$H_e = -\sum_{i}^{N}\sum_{j}^{B} p_{ij} \ln p_{ij}$$

where $p_{ij} = \frac{n_{ij}}{N}$, n_{ij} = number of trees of species *i* in height layer *j*, *N*= total number of trees in the stand, *S* = number of different tree species and *B* = number of height layers (*B* = 3).

The assessment of the dead wood component consisted of (a) number of dead standing trees (b) dead downed trees (c) downed coarse wood pieces (branches with diameter ≥ 5 cm) (d) downed fine wood pieces (small branches with diameter < 5 cm) and (e) stumps. Decay levels of wood decomposition stages (from 1 to 7; with 7 representing the highest decomposition degree) were assessed according to Keller et al. (2004). For each decay level, the number and volume of each component was calculated per hectare.

Table 1 Diversity index

α diversity		
Species richness	$D_{MG} = \frac{S-1}{\ln N}$ Clifford and Stephenson (1975); mod. by Margalef (1998)	$\frac{S}{N}$ Kempton (1979)
Uniformity	$E = \frac{H'}{H_{max}}$ Pielou (1969)	
1-Dominance	$1 - D = 1 - \sum\left(\frac{n_i(n_i - 1)}{N(N-1)}\right)$ Simpson (1949) mod. by Magurran (1988)	$1 - d = 1 - \frac{N_{max}}{N}$ Berger and Parker (1970)
Strata comparison		
Diversity ordering	$H_\delta = \frac{\left(\ln \sum_{i=1}^{S} p_i^\delta\right)}{(1-\delta)}$ Rènyi (1970); δ: order parameter (δ>0; δ<4)	
β diversity index		
Ecosystem variation	β_w=(S/α)-1 Whittaker (1960)	$\beta_R = \frac{S^2}{2r+S} - 1$ Routledge (1977)
Ecosystem similarity	$C_S = \frac{2k}{a+b}$ Sørenson index (1957)	$C_N = \frac{2kN}{aN + bN}$ Quantitative Sørenson index

S: number of tree species; *N*: number of trees; n_i: number of *i* trees in each specie; N_{max}: number of *j* species tree, where *j* is the species with the greatest number of tress; $p_i = n_i/N$ (Maximum likelihood estimator); *H'* is the Shannon - Wiener index (1949); H_{max} = ln *S*; α: mean number of species in the plot; *r*: number of species with overlap distribution; *k*: number of species common to all the strata included in the analysis; *a*: number of species in the first strata; *b*: number of species in the second strata; *aN* : number of trees in the first strata; *bN*: number of trees in the second strata; *kN*: number of trees in the strata of species common to all the strata.

2 Results

2.1 Composition

The primary woody plant genera found in this study in the upper tree canopy included: *Citronella* spp., *Clusia* spp., *Delostoma* spp., *Meliosma* spp., *Morus* spp., *Oreopanax* spp., *Persea* spp., *Ruagea* spp. and *Weinnmania* spp. The lower canopy included *Cestrum* spp., *Eugenia* spp., *Miconia* spp., *Myrcianthes* spp., *Oreocallis* spp., *Palicourea* spp., *Parathesis* spp., *Piper* spp. and *Solanum* spp. (Table 2). *Lower canopy* shrubs included: *Baccaris* spp., *Fucsia* spp., *Piper* spp., *Solanum* spp. and *Vervesina* spp., and the Papilonaceae, Amarillidaceae and Chlorantaceae families. The genus *Chusquea* (Poaceae) was particularly prominent in the grass layer. Although only woody plants were monitored, ferns, lianas and epiphytes, typical of cloud forests, were also common in the studied forest (Figure 2). A significant presence of the Orchidaceae family should also be mentioned, represented by a wide variety of genera such as: *Epidendrum*, *Lepanthes*, *Oncidium* and *Pleurosthallis* (Hildgert de Benavides 2002). The great abundance of Bromeliaceae and Orchidaceae indicates areas of atmospheric air quality (Foster 2001). A detailed woody plant species list is

Table 2 Tree families: the main genera and number of species identified in the forest

Family	NG	Main genus	NS	Family	NG	Main genus	NS
Acanthaceae	1	*Aphelandra*	2	Lamiaceae	1	*Lepechinia*	1
Actinidiaceae	1	*Saurauia*	1	Magnoliaceae	1	*Taluma*	1
Amarillidaceae	1		1	Melastomataceae	3	*Miconia*	6
Araliaceae	1	*Oreopanax**	1	Meliaceae	2	*Ruagea*, Guarea**	2
Anacardiaceae	1	*Mauria*	2	Monimiaceae	1	*Siparuna*	1
Asteraceae	6	*Senecio, Liabum, BaccharisVervesina, Critoniopsis, Fulcaldea*	10	Moraceae	1	*Morus **	1
Araceae	1		1	Myrsinaceae	2	*Myrsine, Parathesis*	2
Berberidaceae	1	*Berveris*	1	Myrtaceae	1	*Myrcianthes, Eugenia*	4
Betulaceae	1	*Alnus*	1	Nominaceae	1	*Siparium sp.*	2
Bignonaceae	1	*Delostoma**	1	Onagraceae	1	*Fuchsia*	1
Boraginaceae	1	*Tournefortia*	1	Papaveraceae	1	*Bocconia*	1
Caprifoliaceae	1	*Viburnum*	1	Piperaceae	1	*Piper*	1
Caricaceae	1	*Vasconcella*	1	Polemoniaceae	1	*Cantua*	1
Coriariaceae	1	*Coriaria*	1	Polygonaceae	2	*Monnina*	2
Cunnonaceae	1	*Weinmannia **	2	Proteaceae	1	*Oreocallis sp*	1
Elaeocarpaceae	1	*Vallea*	1	Rhamnaceae	1	*Rhamnus*	1
Ericaceae	1		1	Rannunculaceae	1	*Clematis*	1
Grossulariaceae	2	*Escallonia*	2	Rubiaceae	2	*Palicourea, Randia*	2
Flacourtiaceae	1	*Xylosma*	1	Sabiaceae	2	*Meliosma**	2
Fabaceae	2	*Erithryna*	2	Saxifragaceae	1	*Escallonia*	1
Guttiferae	1	*Clusia**	2	Solanaceae	5	*Lycianthes, Solanum, Cestrum, Iochroma, Datura*	9
Icacinaceae	1	*Citronella**	2	Urticaceae	1	*Boemeria*	1
Lauraceae	4	*Persea*,Nectandra**	5	Winteraceae	1	*Drimys*	1
				TOTAL	67	TOTAL	88 (96 inc.Ms)

NG=Nos of genus; NS= Nos of species; * indicates the canopy and emergent species.

provided in Appendix 1.

In the ecotone or gap zones of the forest, species such as *Oreocallis grandiflora* (Lam.) R. Br. or *Solanum oblongifolium* Dunal can be found. These are light-demanding, frugal species and the presence of which, may be interpreted as an indication of ecosystem degradation in this forest. They can colonize new gaps in the forest and hinder the establishment of other forest vegetation (Gentry 1982).

Table 3 shows α diversity indices calculated as an average of plot values in each stratum, and their standard deviation. Strata I and II had higher species diversity values. Stratum I displayed higher species heterogeneity than stratum II, which can be observed in the standard deviation. There are two factors which lead to greater diversity in this stratum: firstly, it marks the upper limit of the forest, where a number of ecotone species appear and secondly, it contains some deep, inaccessible areas where rare species are present. The diversity indices reached higher values in this stratum due to the presence of upper ecotone species (Table 3). Stratum III, located in the lower zone, showed lower diversity values, and contained the least number of species and the greatest dominance, as can be clearly seen from the Rènyi curves (Figure 3). The curves for strata I and II crossed over, so they were not comparable. Stratum III differed the most due to alteration by human activities and therefore the strata comparison values were higher for II vs III and III vs I (Table 3).

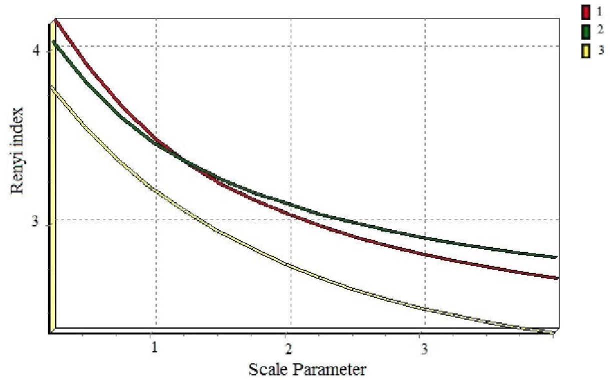

Figure 3 Resultant Rènyi curves for each stratum

2.2 Structure

(a) Horizontal structure: The stand exhibited a J-shape distribution as was expected since it is an uneven-aged stand. The number of stems per hectare (d ≥ 7.5 cm) was lower in Stratum III. In the two upper strata, values were quite similar. Basal area exhibited the same behaviour, decreasing in the lower stratum (Table 4).

(b) Vertical structure: In strata I and II, the dominant height was slightly above 10 m., but in

Table 3 α- and β-diversity values and standard deviation (*SD*)

Species Richness						
Strata	S	*SD*	Margalef	*SD*	Kempton	*SD.*
I	87	10.329	4.229	1.919	0.032	0.601
II	77	5.215	5.023	0.709	0.022	0.043
III	59	11.188	3.724	1.940	0.017	0.056
1-Dominance					Uniformity	
Strata	Simpson	*SD*	Berger-Parker	*SD*	Evenness	*SD*
I	0.819	0.265	0.734	0.251	0.742	0.217
II	0.919	0.028	0.976	0.023	0.907	0.070
III	0.731	0.365	0.800	0.397	0.698	0.354

Ecosystem variation			Ecosystem similarity		
Strata	Whittaker	Routledge	Strata	Sørenson	Sørenson quantitative
I	3.638	0.801	I *vs.* II	0.646	0.601
II	2.837	0.5739	II *vs.* III	0.735	0.634
III	2.748	0.409	III *vs.* I	0.685	0.991

Table 4 Number of trees per ha (*N*), diameter at breast height (DBH), basal area (*G*), Dominant Height according to the Hart index (H_0), Shannon index applied to vertical structure (*H'*), Shannon index applied to vertical structure considering different species (H_e) and their corresponding standard deviations (*SD*).

Strata	Stems (d ≥ 7.5 cm)					Total (d > 0 cm)						Shannon index applied to vertical structure			
	N		DBH		*G*	*N*		DBH		*G*	H_0	*H'*		H_e	
	trees/ha	CV %	cm	*SD*	m²/ha	trees/ha	CV %	cm	*SD*	m²/ha	m	value	*SD*	value	*SD*
I	1764	52.85	16.43	8.01	37.40	5760	52.94	9.81	6.60	43.53	10.69	0.403	0.270	3.921	1.356
II	1746	30.81	17.24	8.00	40.77	6383	41.70	9.58	6.96	46.02	11.30	0.517	0.204	4.459	0.374
III	771	62.24	22.13	11.72	29.68	5259	58.94	9.02	7.42	33.60	18	0.363	1.188	3.308	1.686

Table 5 Number and volume of dead wood elements

Number elements											
Strata	Dead standing trees		Dead downded trees		Lying coarse wood pieces		Lying fine wood pieces		Stumps		total
	N/ha	*SD*	N/ha	*SD*	N/ha	*SD*	N/ha	*SD*	N/ha	*SD*	N/ha
I	258.3	203.2	31	3.2	3,112	137.1	527	18.0	46	3.0	3,974
II	453.57	297.2	36	3.3	7,292	209.3	987	35.0	34	3.4	8,802
III	276.56	271.6	27	2.0	3,683	158.2	1,060	49.1	27	1.9	5,073
Volume											
Strata	Dead standing trees		Dead downded trees		Lying coarse wood pieces		Lying fine wood pieces		stumps		total
	V (m³/ha)	*SD*	V (m³/ha)	*SD*	V (m³/ha)	*SD*	V (m³/ha)	*SD*	V (m³/ha)	*SD*	V (m³/ha)
I	7.40	6.56	2.23	0.34	1.96	0.13	5.46	0.39	0.35	0.07	17.4
II	20.64	14.24	1.14	0.13	4.27	0.30	17.90	0.80	0.16	0.02	44.11
III	9.54	13.89	2.28	0.30	2.73	0.11	17.98	0.98	0.22	0.02	32.75

stratum III, the value was 18 m. The Shannon index applied to the vertical structure returned a low value, indicating a vertical structure of little significance, probably because only 2 recognisable vertical layers were present (Table 4). The values obtained were very high, however, where different species were considered when applying the index to the vertical structure (Table 4). The second stratum displayed the greatest heterogeneity in the vertical structure.

2.3 Dead wood

Abundant dead wood in an advanced state of decay was found in the forest (Figure 4). The quantity of coarse and fine woody pieces was smaller in stratum I (Table 5). The number of trees was also lower. The volume of dead wood was notable throughout the forest (Table 5) in spite of the fact that local people sometimes extract firewood.

3 Discussion

In order to gain a clear understanding of the forest and thus develop adequate strategies for sustainable management, it is necessary to assess the biodiversity (Pommerening 2006). This paper provides ample information with respect to tropical montane cloud forest in the Andean area.

3.1 Composition

Different compositions exist from one zone to another. In general, this is due to factors such as the demands of different species for light or shade or other environmental factors (Clark and Clark 1992). Human disturbances also play an important role (Aubad et al. 2008).

Although Lauraceae family are either a dominant or co-domintant family in many relatively well preserved cloud forests around the world: in China (Lü et al 2010, Shi and Zhu 2009), Philipines (Penafiel 1994), Meso-america (Nadkarni et al. 1995), Ecuador (Sarmiento 1993) and Malasia (Kitayama 1994). In the studied forest, Lauraceae is not the dominant family, other families such as Sabiaceae being more abundant. *Meliosma* (Sabiaceae) is an emblematic genus in Andean cloud forest (Gentry 1992).

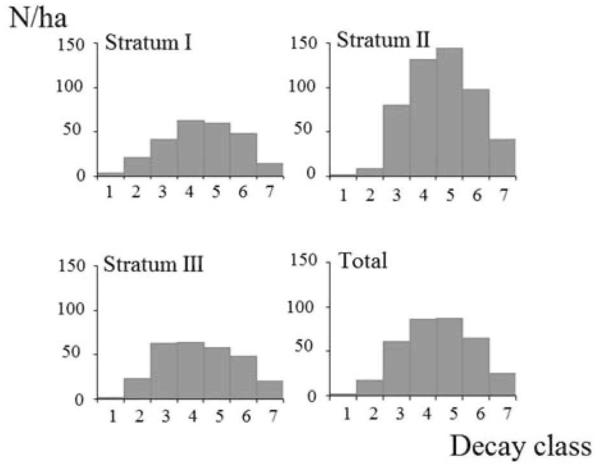

Figure 4 Number of dead standing trees per hectare in each stratum and for the forest as a whole, classified according to decay class

Regarding the α-diversity values obtained, the inner zone of the forest displays the highest biodiversity value and the lowest standard deviation (Table 3). The increased elevation (from stratum II to I), causes a decrease in diversity values, as was expected. However in the lower zone (stratum III) biodiversity values are significantly lower. In this stratum there is a passable track which brings increased human pressure and disturbance. Hence, the biodiversity values increase with altitude (from stratum III to II), whereas the observed pattern in tropical mountains is the opposite, decreasing with altitude (Gentry 1995). The areas with the greatest levels of diversity in Andean forests are found between 500-2,000 m (Gentry 1988), which would correspond to stratum I at our study site. In the studied forest, the proximity of human activity has had a greater effect on biodiversity than environmental and gradient factors, once again revealing the fragility of the cloud forest ecosystem. In a study conducted in an Amazonian Peruvian hillside forest, the highest value recorded was 156 species/ha (Gomez-Peralta et al. 2008), which is higher than the values recorded in the present study (~80 species/ha, Table 3). However, in other studies undertaken in Amazonian hillside forests, the biodiversity values recorded are similar to those reported in this study (120 species in a montane forest, La Torre-Cuadros et al. 2007). Colombian Amazonian montane forest was considered the most important in the world in terms of biodiversity (Gentry 1982) although the richness value recorded in Colombia was 72.3 species/ha ±18 (Aubad et al. 2008), which is only a little higher than the value recorded in our study. The species richness values are slightly lower in meso-american forests (114 species in the forest, Nadkarni et al. 1995), which may be due to lower precipitation rates, greater distance from the equator and the absence of Amazonian influence.

3.2 Structure

The forest displays an uneven-aged stand structure, with a wide mix of ages within the forest (Table 4). Similar densities (~5,500 trees/ha) and diameter distributions (J-shape) have been identified in other studies of cloud forests, such as that undertaken at Monteverde, Costa Rica (Nadkarni et al. 1995). In some cloud forests, the basal area values recorded are higher than those found in our analysis (we have recorded ~40m²/ha (Table 4), and Nadkarni et al. (1994) 73.8 m²/ha, García-Santos et al. (2009) 68 m²/ha, Arévalo and Fernandez-Palacios (1998) 50.57 m²/ha) while in others, the values are similar (48 m²/ha; Oosterhoorn and Kappelle 2000) or lower (19 m²/ha, La-Torre et al. 2007). Differences in the diameter distribution from one area of the forest to another may be related to different disturbance regimes or micro-habitat conditions.

In the studied forest, almost 70% of trees have a DBH of less than 7.5 cm (Table 4). The fact that these trees exist in large numbers constitutes an important element in the ecosystem because, in spite of their small DBH, many of them form a broad leaved cover a few meters above the ground and reduce the amount of light reaching the soil (Montgomery 2004). Stratum III, which has undergone the greatest modification in recent times, presents the greatest recruitment. It should be emphasized that the recruitment is partly composed of secondary forest species whereas the dominant older trees tend to be potential Andean montane forest species. This situation highlights the beginning of a possible degradation of the ecosystem, in agreement with Ledo et al. (2009).

The stand stature values (maximum height of 10 to 18 m in the analysed forest, Table 4) are similar to those recorded in another Peruvian Andean forest (a maximum of 15 m height, La Torre-Cuadros et al. 2007) but lower than those found on the Peruvian Amazonian hillside (medium height: 14.3 to 15.5 m, Gomez-Peralta et al. 2008). Furthermore, due to the frequency of cloud contact (Bruijnzeel and Veneklaas 1998), the stature of the vegetation in cloud forests is reduced (Foster 2001; Hamilton et al. 1994; Stadmuller 1987), ranging from 5 - 10 m in the tropical montane cloud forest in Yunnan (Shi and Zhu 2009), to 15 m (Gomez-Peralta et al. 2008) in central Peru. However, these observations conflict with those reported in Costa Rica (Oosterhoorn and Kappelle 2000) where heights of 30-50 m were recorded.

The Shannon index applied to the vertical structure returns a low value (~0.45), indicating a vertical structure of little significance, probably because only 2 recognisable vertical layer are present (Table 4). The Shannon index involves the height being divided into arbitrary classes in order to calculate proportions; the number of classes used alters the maximum value of the index. This index is also sensitive to tree size and a change in the number of defined classes would invariably change the value of the index (Staudhammer and LeMay 2001). The values obtained are very high, however, where different species are considered when applying the index to the vertical structure (Table 4). The second stratum displays the greatest heterogeneity in the vertical structure.

3.3 Dead wood

Decaying wood is an important element in functional biodiversity (Ferris and Humphrey 1999) and in the case of cloud forests; it appears to play an essential role in the ecosystem. In Hawaiian montane forests, fallen logs provide the most common germination sites for woody species; between 50 and 70% of natural regeneration occurs on decaying logs in these forests (Goldman et al. 2008). These logs also create a diversity of microhabitats for a wide variety of organisms (Wilcke 2005). Hence, decaying wood has been shown to be critical for the regeneration and structure of cloud forests (Santiago 2000).

There is a large volume of woody debris in the forest (~300 dead standing trees/ha, ~40 m^3/ha), much of it in an advanced state of decay (Table 5). This probably indicates, as reported in previous research (Bruijnzeel and Veneklaas 1998), that the speed of recycling is lower than in other ecosystems and that dead wood may remain undecomposed on the forest floor over a long period of time due to the absence of decay bacteria (Santiago 2000) caused by wet soils at lower temperatures in the cloud forest.

The obtained decayed wood values in this study (regarding volume and decay status, Table 5) are similar to those reported for some cloud forests (up to 23 t/ha in Equador, Wilcke et al. 2005) but lower than in others (Hawai- 237.5 m^3/ha, Santiago 2000). The volume of decayed wood in the study area is lower than the volume found in tropical dry forests (35.68 m^3; Grove 2001). However, the ratio of the number of living trees to the amount of coarse woody debris is similar for both types of forest.

3.4 Final remarks and conclusions

In this study, the widely held view of tropical montane cloud forests as true enclave of biodiversity (hotspot) has been confirmed. The real value of cloud forests lies in their functionality and biodiversity (Wilcke et al. 2005). Water catchment is essential to the local agricultural activity. In the Andean range, these forests also serve to avoid erosion and landslides, which currently pose a serious threat to local people. Because cloud forests are fragile ecosystems, the effects of deforestation and other damaging activities are irreversible (Hamilton 1995). Therefore, adequate management and monitoring is essential to preserve cloud forest ecosystems in their present form.

Acknowledgements

The field work has been mainly supported by Nature and Culture International (NCI-Perú) and partially funded through a Grant from the Universidad Politécnica de Madrid. We are greatly indebted to Wilder Caba Culquicondor, Wylliam Calle Rivera and Marcelino Huacchillo Espinoza for their help in the field work. The authors wish to thank Adam Collins for the English language revision. We thank the anonymous reviewers and the editor for their helpful and very valuable comments on a previous version of the manuscript.

Appendix 1: List of the species identified in the forest

Family	Species	Endemic§	Threath*
Acanthaceae	*Aphelandra acanthifolia* Hook	Ecuador	
	Aphelandra sp.		
Actinidiaceae	*Saurauria* sp.		
Amarillidaceae	sp.		
Araliaceae	*Oreopanax raimondii* Harms.	Perú	VU-D2
Anacardiaceae	*Mauria heterophylla* (H. B. K.) ¿		
Anacardiaceae	*Mauria* sp.		
Asteraceae	*Senecio* sp.		
Asteraceae	*Liabum* sp.		
Asteraceae	*Baccharis* sp.		
Asteraceae	*Verbesina piurana* Sagástegui	North Peru	NT
Asteraceae	*Critoniopsis sevillana* (Cuatrec.) H. Rob.	Ecuador	VU- B1ab(iii)
Asteraceae	*Fulcaldea laurifolia* (Humboldt & Bonpland) Poiret ex Lessing	South Ecuador, North Peru	
Asteraceae	*Dasyphyllum* sp.		
Asteraceae	*Gynoxis* sp.		
Araceae	sp.		
Berberidaceae	*Berberis lutea* RandP		
Betulaceae	*Alnus acuminata* H. B. K.		Lower Risk
Bignonaceae	*Delostoma integrifolium* D. Don		
Boraginaceae	*Tournefortia* sp.		
Caprifoliaceae	*Viburnum* sp.		
Caricaceae	*Vasconcella* sp.		
Coriariaceae	*Coriaria Ruscifolia* L.		
Cunnonaceae	*Weinmannia ayavacencis* O. Schmidt	X	
Elaeocarpaceae	*Vallea stipularis* Mutis ex L.f.		
Ericaceae	sp.		
Grossulariaceae	*Escallonia pendula* (RandP) Person		
Grossulariaceae	*Escallonia* sp.		
Flacourtiaceae	*Xylosma cordatum* (Humboldt, Bonpland & Kunth) Gilg		
Fabaceae	*Erithryna* sp.		
Guttiferae	*Clusia flaviflora* Engl		
Icacinaceae	*Citronella incarum* (J. F. Macbr.) R. A. Howard		
Icacinaceae	*Citronella* sp.		
Lauraceae	*Persea* sp.		
Lauraceae	*Nectandra* sp.		
Lauraceae	*Ocotea* sp.		
Lauraceae	*Ocotea* sp.		
Lamiaceae	*Lepechinia* sp.		
Magnoliaceae	*Taluma* sp.		
Melastomataceae	*Miconia media* (D. Don) Naudin	South Ecuador, North Peru	
Melastomataceae	*Miconia denticulata* Naudin		
Melastomataceae	*Miconia firma* Macbr.	North Peru	

-To be continued-

-Continued-

Appendix 1: List of the species identified in the forest

Family	Species	Endemic§	Threath*
Melastomataceae	*Axinaea oblongifolia* (Cogniaux) Wurdack	South Ecuador, North Peru	
Melastomataceae	*Brachyotum* sp.		
Meliaceae	*Ruagea glabra* Triana & Planchon		
Meliaceae	*Trichilia* sp.		
Meliaceae	*Guarea* sp.		
Monimiaceae	*Siparuna muricata* (Ruiz & Pavón) A.DC.		
Moraceae	*Morus insignis* Bureau		
Myrsinaceae	*Parathesis* sp.		
Myrsinaceae	*Myrsine latifolia* (Ruiz and Pavon) Sprengel		
Myrtaceae	*Myrcianthes fimbriata* (Kunth) McVaugh	South Ecuador, North Peru	
Myrtaceae	*Myrcianthes discolor* (Kunth) McVaugh		
Myrtaceae	*Myrcianthes fragrans* (Sw.) McVaugh		
Myrtaceae	*Eugenia* sp.		
Nominaceae	*Siparium* sp.		
Onagraceae	*Fuchsia ayavacensis* H.B.K.	X	
Papaveraceae	*Bocconia integrifolia* Humb. & Bonpl.		
Piperaceae	*Piper elongatum* (Poir. ex Vahl) C.DC		
Polemoniaceae	*Cantua* sp.		
Polygonaceae	*Monnina pilosa* H. B. & K. var. *¿glabrescens Ferreyra*	South Ecuador, North Peru	
Polygonaceae	*Monnina ligustrifolia Kunth in Humboldt and al*	South Ecuador, North Peru	
Proteaceae	*Oreocallis grandiflora (Lamarck) R. Brown*	South Ecuador, North Peru	
Rhamnaceae	*Rhamnus sp*		
Rannunculaceae	*Clematissp*		
Rubiaceae	*Palicourea amethystina (Ruiz and Pav.) DC.*		
Rubiaceae	*Randia boliviana Rusby*		
Sabiaceae	*Meliosma* Ms1		
Sabiaceae	*Meliosma* Ms2		
Saxifragaceae	*Escallonia sp*		
Solanaceae	*Datura sp*		
Solanaceae	*Cestrum auriculatum* L'Hér		
Solanaceae	*Iochroma squamosum* S.Leiva, and V.Quipuscoa	X	
Solanaceae	*Lycianthes inaequilatera (Rusby) Bitter.*		
Solanaceae	*Solanum* sp		
Solanaceae	*Solanum*sp		
Solanaceae	*Solanum oblongifolium* Dunal		
Solanaceae	*Solanum* sp		
Urticaceae	*Boehmeria caudata Sw.*		
Winteraceae	*Drimys granadensis L.f.*		

§ According to the Missouri botanical garden <http://www.tropicos.org> (2010)
* According to the IUCN Red List of Threatened Species. Version 2010.4. <http://www.iucnredlist.org> (2010)
It should be pointed out that many of the species found have not been classified by the IUCN as insufficient data exists on the species to allow the state of their conservation status to be determined

References

Arévalo JR, Fernandez-Palacios JM (1998) Treefall gap characteristics and regeneration in the laurel forest of Tenerife. Journal of Vegetation Science 9: 297-306.

Aubad J, Aragón P, Olalla-Tárraga M, Rodríguez M (2008) Illegal logging, landscape structure and the variation of tree species richness across North Andean forest remnants. Forest Ecology and Management 255: 1892-1899.

Berger WH, Parker FL (1970) Diversity of planktonic foraminifera in deep-sea sediments. Science 168: 1345-1347.

Bruijnzeel LA, Veneklaas EJ (1998) Climatic conditions and tropical montane forest productivity: the fog has not lifted yet. Ecology 79: 3-9.

Bubb P, May I, Miles L, Sayer J (2004) Cloud forest Agenda. UNEP-WCMC, Cambridge, UK.

Cavelier J, Jaramillo M, Solis D, et al. (1997) Water balance and nutrient inputs in bulk precipitation in tropical montane cloud forest in Panama. Journal of Hydrology 193: 83-96.

Churchill SP, Balslev H, Forero E, et al. (1995) Biodiversity and conservation of Neotropical montane forest. In: Proceedings of the Neotropical Montane Forest Biodiversity and Conservation Symposium. The New Botanical Garden, Bronx, New York, USA, 21±26 June 1993.

Clark DA, Clark DB (1992) Life history diversity of canopy and emergent trees in a neotropical rain forest. Ecological Monographs 62: 315-344.

Clifford HT, Stephenson W (1975) An Introduction to Numerical Classification. Academic Press, New York, USA.

Ferris R, Humphrey JW (1999) A review of potential biodiversity indicators for application in British forests. Forestry 72: 313-328.

Foster P (2001) The potential negative impacts of global climate change on tropical montane cloud forests. Earth Sciences Review 55: 73-106.

Freile JF, Santander T (2005) Important bird areas in Ecuador. In: Birdlife Internacional (ed.) Important Bird Areas Tropical Americas - Priority sites for biodiversity conservation, Vol. 14. in BirdLife International and Conservation International Quito, Ecuador [Áreas importantes para la conservación de las Aves en Ecuador. In: Birdlife Internacional (ed.) Áreas Importantes para la Conservación de las Aves en los Andes Tropicales: sitios prioritarios para la conservación de la biodiversidad].

García-Santos G, Bruijnzeel LA, Dolman AJ (2009) Modelling canopy conductance under wet and dry conditions in a subtropical cloud forest. Agricultural Forest and Meteorology 149(10): 1565-1572.

Gentry AH (1995) Patterns of diversity and floristic composition in neotropical montane forest. In: Churchil SP (ed.) Biodiversity and Conservation of Neotropical Montane Forest. The New York Botanical Garden, New York, USA.

Gentry AH (1992) Diversity and floristic composition of Andean forest of Peru and adjacent countries: implication for their conservation. In: Young KR, Valencia N (eds.) Biogeography, ecology and conservation of montane forest in Peru, Vol. 21. Museum of Natural History, UNMSM [Biogeografía, ecología y conservación del bosque montano en el Perú, Vol. 21. Memorias Museo de historia natural, UNMSM].

Gentry AH (1988) Changes in plant community diversity and floristic composition on environmental and geographic gradients. Annals of the Missouri Botanical Garden 75: 1-34.

Gentry AH (1982) Patterns of neotropical plant species diversity. Evolutionary Biology 15: 1-84.

Goldman RL, Goldstein LP, Daily GC (2008) Assessing the conservation value of a human-dominated island landscape: Plant diversity in Hawaii. Biodiversity and Conservation 17: 1765-1781.

Gomez-Peralta D, Oberbauer SF, McClain ME, et al. (2008) Rainfall and cloud-water interception in tropical montane forests in the eastern Andes of Central Peru. Forest Ecology and Management 255: 1315-1325.

Grove SJ (2001) Extent and composition of dead wood in Australian lowland tropical rainforest with different management histories. Forest Ecology and Management 154: 35-53.

Grubb PJ, Lloyd JR, Pennington TD, et al. (1963) A comparison of montane and lowland rain forest in Ecuador I. The forest structure, physiognomy, and floristics. Journal of Ecology 51: 567-601.

Hamilton LS (1995) Mountain Cloud Forest Conservation and Research: A Synopsis. Mountain Research Development 15: 259-266.

Hamilton LS, Juvick JO, Scalena F (1994) Tropical montane Cloud forest. Springer-Verlag, New York, USA.

Hildgert de Benavides N (2002) Towards the conservation of Cuyas forest- baseline information. Proaves-Perú [Hacia la conservación del Bosque de Cuyas-información de base].

Holdridge LR (1967) Life Zone Ecology. Tropical Science Center. San Jose, Costa Rica.

Hunter ML Jr (1990) Wildlife, Forests, and Forestry: Principles of Managing Forests for Biological Diversity. Prentice Hall, Englewood Cliff, USA.

Keller M, Palace M, Asner GP, et al. (2004) Coarse woody debris in undisturbed and logged forests in the eastern Brazilian Amazon. Global Change Biology 10: 784-795.

Kempton RA (1979) The structure of species abundance and measurement of diversity. Biometrics 35: 307-321.

Kitayama K (1994) Biophysical conditions of the montane cloud forests of Mount Kinabalu, Sabah, Malaysia. In: Hamilton LS, Juvik JO, Scatena FN (eds.) Tropical Montane Cloud Forests, Springer-Verlag, New York, USA.

Köppen W (1931) Grundriss der klimakunde. Walter de Grwyter, Berlin.

Kukkonen M, Hohnwald S (2009) Comparing floristic composition in tree fall gaps of certified, conventionally managed and natural forests of northern Honduras. Annals of Forest Science 66: 809.

La Torre-Cuadros M, Salvador Herrando-Pérez S, Young K (2007) Diversity and structural patterns for tropical montane and premontane forests of central Peru, with an assessment of the use of higher-taxon surrogacy. Biodiversity and Conservation 16: 2965-2988.

Ledo A, Montes F, Condés S (2009) Species dynamics in a montane cloud forest: Identifying factors involved in changes in tree diversity and functional characteristics. Forest Ecology and Management 258: S75-S84.

Lü XT, Yin JX, Tang JW (2010) Structure, tree species diversity and composition of tropical seasonal rainforests in Xishuangbanna, south-west China. Journal of Tropical Forest Science 22(3): 260-270.

Luna-Vega I, Alcantara O, Espinosa D (2001) Biogeographical affinities among neotropical cloud forest. Plant System Evolution 228: 229-239.

Magurran AE (1988) Ecological Diversity and Its Measurement. Princeton University Press, Princeton, USA.

Margalef R (1998) Ecology. Ediciones Omega. Barcelona [Ecología]

Meyer P (1999) Determination of development phases and diversity of forest texture. Allgemeine Forst- und Jagdzeitschrif 170(10–11): 203–211 [Bestimmung der Waldentwicklungsphasen und der Texturdiversität in Naturwäldern].

Montgomery RA (2004) Effects of understory foliage on patterns of light attenuation near the forest floor. Biotropica 36(1): 33-39.

Munishi PKT, Shear TH, Wentworth T, et al. (2007) Compositional gradients of plant communities in submontane

rainforest of eastern Tanzania. Journal of Tropical Forest Science 19(1): 35-45.
Myers N, Mittermeier RA, Mittermeier CG, et al. (2000) Biodiversity hotspots for conservation priorities. Nature 403: 853-858.
Nadkarni NM, Matelson TJ, Haber WA (1995) Structural characteristics and floristic composition of a neotropical cloud forest, Monteverde, Costa Rica. Journal of Tropical Ecology 11: 481-495.
Nadkarni NM, Schaefer D, Matelson TJ, et al. (1994) Biomass and nutrient pools of canopy and terrestrial components in a primary and a secondary montane cloud forest, Costa Rica. Forest Ecology and Management 198: 223-236.
Oosterhoorn M, Kappelle M (2000) Vegetation structure and composition along an interior-edge-exterior gradient in a Costa Rican montane cloud forest. Forest Ecology and Management 126: 291-307.
Patiño J, González-Mancebo JM, Fernández-Palacios JM et al (2009) Short-term effects of clear-cutting on the biomass and richness of epiphytic bryophytes in managed subtropical cloud forests. Annals of Forest Science 66: 609.
Penafiel SR (1994) The biological and hydrological values of the mossy forests in the Central Cordillera mountains, Philippines. In: Hamilton LS, Juvik JO, Scatena FN (eds.) Tropical Montane Cloud Forests. Springer-Verlag, New York, USA.
Pielou EC (1969) An introduction to mathematical ecology. Wiley Interscience. John Wiley & Sons, New York, USA.
Pommerening A (2006) Evaluating structural indices by reversing forest structural analysis. Forest Ecology and Management 224: 266-277.
Rènyi A (1970) Probability Theory. North Holland Publishing Company, Amsterdam.
Romero C, Baigorria GA, Stroosnijder L (2007) Changes of erosive rainfall for El Niño and La Niña years in the northern Andean highlands of Peru. Climatic Change 85: 343-356.
Routledge RD (1977) On Whittaker's components of diversity. Ecology 58:1120-1127.
Santiago L (2000) Use of coarse wood debris by the plant community of a Hawaiian Montane Cloud Forest. Biotropica 32: 633-641.
Sarmiento FO (1993) Human impacts on the cloud forests of the upper Guayllabamba river basin, Ecuador, and suggested management responses. In: Hamilton LS, Juvik JO, Scatena FN (eds) Tropical Montane Cloud Forests, Springer-Verlag, New York, USA.
Schulze ED, Mooney HA (1994) Ecosystem function of biodiversity: a summary. Biodiversity and Ecosystem Function. Springer-Verlag, New York, USA.
Shannon CE, Wiener W (1949) The Mathematical Theory of Communication. Urbana University of Illinois Press, Chicago, USA.
Shi J, Zhu H (2009) Tree species composition and diversity of tropical mountain cloud forest in the yunnan, soutwestern china. Ecological Research 24: 83-92.
Simpson HE (1949) Measurement of Diversity. Nature 163: 688-688.
Sørensen T (1957) A method of establishing groups of equal amplitude in plant sociology based on similarity of species and its application to analyses of the vegetation on Danish commons. Biologiske Skrifter / Kongelige Danske Videnskabernes Selskab (4): 1–34.
Stadmuller T (1987) Cloud forests in the humid tropics: a bibliographic review. United Nations University, Costa Rica. Centro Agronomico Tropical de Investigacion y Ensenanza, Tokyo, Japan.
Staudhammer CL, LeMay VM (2001) Introduction and evaluation of possible indices of stand structural diversity. Canadian Journal of Forest Research 31: 1105-1115.
Van der Werff H, Consiglio T (2004) Distribution and conservation significance of endemic species of flowering plants in Peru. Biodiversity and Conservation 13: 1699-1713.
Whittaker RH (1960) Vegetation of the Siskiyou Mountains, Oregon and California. Ecological Monographs 30: 279–338.
Whitmore TC (1998) An introduction to tropical rain forests. 2nd ed. Oxford University Press, Oxford, UK.
Wilcke W, Hess T, Bengel C, Homeier J, Valarezo C, Zech W (2005) Coarse woody debris in a montane forest in Ecuador: mass, C and nutrient stock, and turnover. Forest Ecology and Management 205: 139-147.
Young KR, León B (1993) Distribution and conservation of Perú's Montane Forest: Interactions between the biota and human society. In: Hamilton LS, Juvik JO, Scatena FN (eds.) Tropical Montane Cloud Forests, Springer-Verlag, New York, USA.